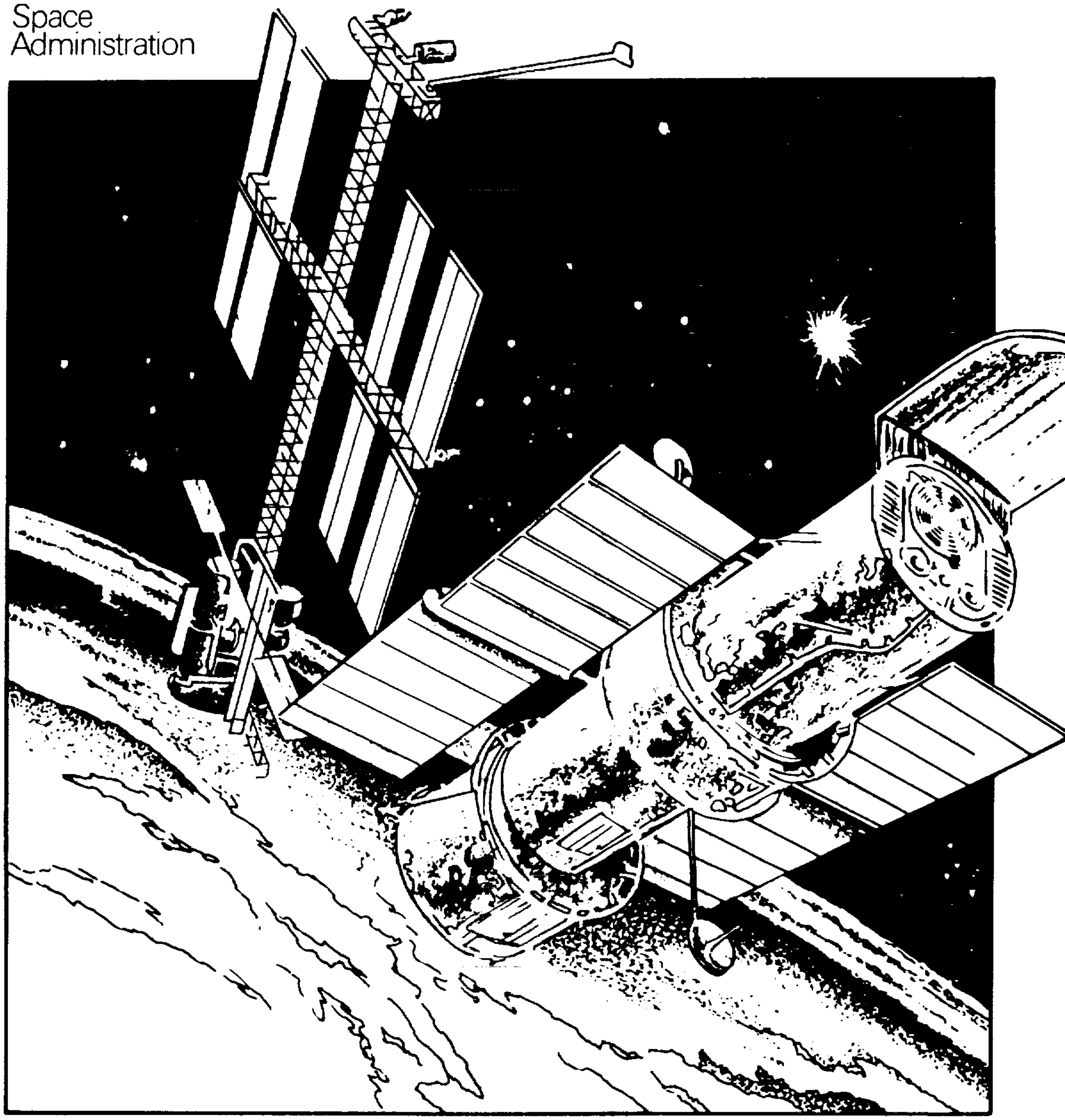
Volume 5
Space Platforms for
Astrophysics

NASA
National
Aeronautics and
Space
Administration



Astrophysics Utilization of the Space Station

(NASA-TM-107884) WORKSHOP ON ASTROPHYSICS UTILIZATION OF THE SPACE STATION. VOLUME 5: SPACE PLATFORMS FOR ASTROPHYSICS (NASA) 25 p

N92-70715

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ASTROPHYSICS AND THE SPACE STATION

VOLUME 5

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SPACE PLATFORMS FOR ASTROPHYSICS

In the first four volumes of this report, we described how the Space Station can be used as an observation base, as a servicing center, and as an assembly base for astrophysics missions. In this last volume, we describe how the Space Station may lead to a new generation of spacecraft for our missions and how they might be used. The new generation we call "space platforms". They are likely to come in a spectrum of sizes to accommodate a spectrum of missions, and they are characterized by their long lives--made possible by the Space Station.

Nearly every astrophysics mission is a candidate for a "space platform" of some type, because only a very few missions require orbits that are incompatible with the Space Station. Our flagships are our great observatories; however, with the Space Station, it makes sense to develop sustained spacecraft, space platforms, for Explorer missions and perhaps even small, developmental missions.

This volume begins with a discussion of the new generation of spacecraft, describes technical aspects of spacecraft systems that may become part of future platforms, and ends with a set of scientifically important missions that are best accommodated on these platforms.

(Editor's Note: At the Workshop on Astrophysics Utilization of the Space Station, discussion focused on moderate and smaller, Explorer-class missions, their scientific importance, and the impact of the Space Station on their implementation. Results from the Panel on Space Platforms for Astrophysics, emphasizing these missions, are the main subject of this report. Since the Workshop, new and significant information has been developed on Space Station platforms and how they might be used for NASA's program of major, orbiting observatories, and we are including the new results because of the relevance to the work by the panel. We have reviewed the new information with members of the scientific community and have incorporated the information in a special section, "Space Station Platforms for AXAF and SIRTF.")

NEW GENERATION OF SPACECRAFT

When the Shuttle was under development, it was clear that we were acquiring a new resource for servicing spacecraft in orbit, and it made sense to begin developing spacecraft that could be maintained and updated. This could only be done for a facility important enough to justify the servicing, and at the same time, being serviceable and having a long operational lifetime justified the expense of a major observatory. The convergence of servicing capability and scientific need defined the observatories of the Shuttle generation, and none better than the Hubble Space Telescope (HST) with its orbital replacement units (ORUs) for both focal-plane instruments and spacecraft subsystems. In the same generation are the Gamma Ray Observatory (GRO) and the smaller solar physics platform that carries the Solar Maximum Mission (SMM).

Space Station and Long-Lived Spacecraft

It is a general engineering principle that for a complex system to endure, it must be designed to be fixed. A key design feature highlighted during the repair of SMM is that accessibility is the most important factor governing whether a subsystem can be repaired in orbit. From this principle, a system of servicing echelons has been defined and is described for the first time in Volume 3 of this report.

We have not designed before truly long-lived spacecraft following these principles. Our enduring planetary missions are beyond our reach, and the closest we have come before the Space Station has been to plan for replacing some modules in orbit and scheduling major overhauls on the ground. Now, with the Space Station on the horizon, NASA has decided to do all the servicing of HST in orbit; studies have shown that this is possible even though HST was not originally designed for complete independence from ground servicing. For the Space Station generation of astrophysics observatories--the Advanced X-Ray Astrophysics Facility (AXAF) and the Space Infrared Telescope Facility (SIRTF)--accessibility and modularity will be the baseline: they will be designed from the beginning for complete independence from ground servicing.

The Space Station is just as essential for the viability of smaller platforms as it is for observatories. The possibility of using the Station as a transportation node solves an important problem that has inhibited investment in permanent, orbiting facilities for a series of payloads like the Explorers: it is very difficult to schedule a Shuttle launch to rendezvous with a spacecraft for a small payload. Small payloads must share launches with others, and finding payloads with compatible orbital requirements is very difficult. The transportation and storage facilities of the Space Station make it possible for private companies to begin investing in space platform services that can be leased to payloads.

The general requirements for serviceability are given in Volume 3, but key points for a discussion of platforms are:

- Design everything so that it is accessible
- Obtain the required orbital transfer capability
- Design platforms for total compatibility with the Station.

SPACE STATION PLATFORMS FOR AXAF AND SIRTF

Requirement for Long Life

It is the scientific importance and versatility of the major observatories and their complementary capabilities that lead to the requirement of mission lifetime measured in decades. HST, AXAF, and SIRTF together essentially cover the spectrum from the far infrared through x-rays, and as long as GRO remains operational, we will have coverage through gamma rays. Many of the most important problems we know about, including the source of power in quasars and the radiation mechanisms of pulsars, require multi-spectral observations to determine what is going on, and it is long life that

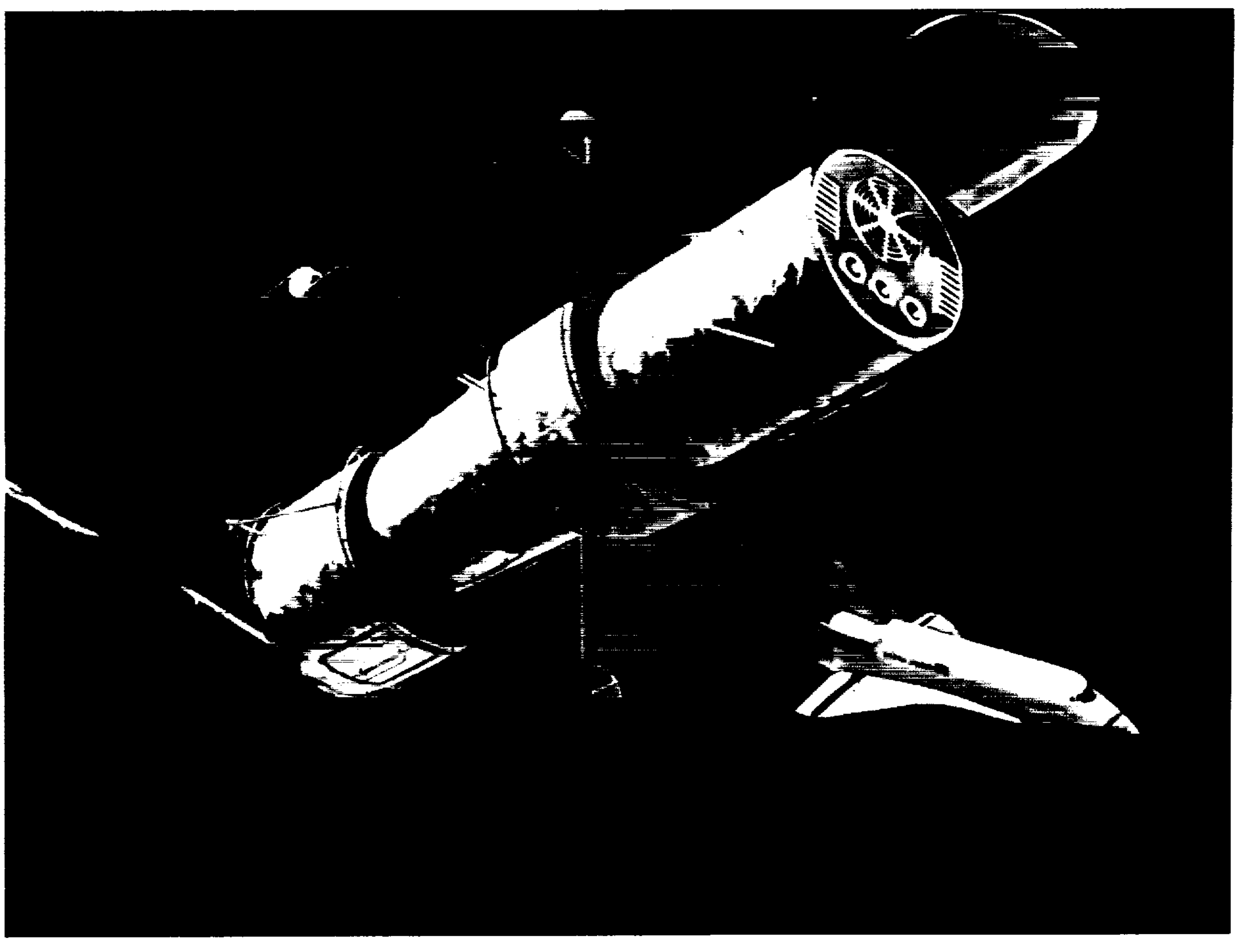

FIGURE 5.1. THE ADVANCED X-RAY ASTROPHYSICS FACILITY (AXAF)

AXAF will be as significant an advance in x-ray astronomy as the Hubble Space Telescope is for visible and ultraviolet astronomy. Launch of AXAF is planned for the early 1990's.

makes the multispectral capability possible while maintaining the traditional, few-year separation between starts of major observatories.

In addition, AXAF, SIRTF, and HST will provide high quality images of cosmic sources in x-rays, infrared, visible, and ultraviolet light to a set of instruments that are very sensitive, powerful, and, for the most part, capable of being replaced with even more powerful instruments. These three observatories will not become obsolete for many decades. Although GRO will not last that long, its primary objective is to perform a sensitive survey of the sky at all gamma-ray wavelengths, and its data base will extend coverage of all objects to the highest energies.

The great orbiting observatories can be compared to the observatories on the ground which have not become obsolete because instrumentation has made such great advances. But there is another reason: we are in a time of great discovery as we observe the universe. Astrophysical investigations are finding one or two entirely new, major phenomena each year, and although this rate of discovery cannot continue indefinitely, we do not see any decline yet. When we attempt to estimate how much there is left to discover, we find that we may be aware of less than half of the major phenomena that will be studied by astronomers over the next fifty years.

Attributes of AXAF and SIRTF Platforms

With our definition of platforms as sustained spacecraft, our requirement for decades of mission life for the AXAF and SIRTF spacecraft makes them space platforms. Concepts for SIRTF and AXAF are going to be judged on the life-cycle costs for 10 and 15 years of operation.

The modular approach has already been proven with SMM, GRO, and HST and is expected to be more important for AXAF and SIRTF. Because AXAF and SIRTF have such similar requirements, we expect that the modules could be common to both missions. As part of this approach, the modules should:

- Use Space Station protocols and standards in the command and data handling subsystem so that the communications interface with the Space Station during servicing will conform with the Space Station standards.
- Use Space Station standards in the power and thermal subsystem to integrate with the Space Station interface during servicing.
- Use Space Station standards for attitude and spacecraft control so that capture, manipulation, and berthing will be common with other Space Station systems.
- Be able to fit through the Space Station airlock so that they can be serviced at the component level in a pressurized environment (Echelon-3 servicing).

Other technical requirements for AXAF and SIRTF are given in Table 5.1 and compared with HST.

The great observatories will become true "space platforms" of the space station era when AXAF and SIRTF meet these requirements and provided that the Space Station has an airlock large enough to accommodate the entry of HST modules. The coming generations of spacecraft and instrument modules for HST and the other great observatories are being designed to be serviced in the shirtsleeve environment.

TABLE 5.1. COMPARISON OF KEY TECHNICAL REQUIREMENTS FOR AXAF, SIRTF, AND HST

Parameter	AXAF	SIRTF	HST
Launch Year	1992*	1993*	1986
Mission Duration (yrs)	15	10	15
Launch Mass (kg)	10,000	7,250	11,600
Power (W)	1200 (regulated)	1859	2500
Pointing Accuracy (arcsec)	30	0.15	0.01
Pointing Stability	0.5 (for 10 sec)	0.10	0.007 (for 12 hrs)
Data Rates	48 kbps (science) 16 kbps (eng)	300 kbps	1024 kbps (telescope)
TDRSS (Data Transmission) Services**			
Forward	125 bps (MA) or 1 kbps (SA)	<10 kbps	125 bps or 1 kbps (SA or MA)
Return	512 kbps (SA)	<3Mbps (SA) or 50 kbps (MA)	1Mbps (SA)

* For planning purposes only
**SA = Single access
MA = Multiple access

PLATFORMS FOR MODERATE AND EXPLORER MISSIONS

Astrophysics missions with considerably less complexity than AXAF and SIRTF can be accommodated by a number of concepts. Among these are dedicated and multiuser platforms that would be available from the government or private sector.

Multimission Modular Spacecraft (MMS)

The MMS is a standard spacecraft bus designed to incorporate standard modular subsystems which provide power regulation, energy storage, attitude control, propulsion, and communication and data handling functions for a wide range of experimental or operational space missions. The MMS can also be adapted to accept mission unique items that are compatible with its multiplex-data bus. The MMS provides autonomous operation through the use of an on-board computer, which is capable of performing such tasks as attitude control, ephemeris computation, stored command processing, power management, thermal control, and payload operations. Spacecraft communications are accomplished through both the NASA Ground/Space Tracking and Data Network (GSTDN) and the Tracking and Data Relay Satellite System (TDRSS).

The MMS is designed to be fully compatible with both expendable launch vehicles and the NASA Space Transportation System (STS). The STS compatibility is accomplished through the use of the MMS Flight Support System, which was designed and built for use in conjunction with the Shuttle orbiter for the on-orbit servicing of MMS type satellites. MMS spacecraft are presently in operation on the Solar Maximum Mission observatory and on both the Landsat-4 and Landsat-5 earth observation satellites.

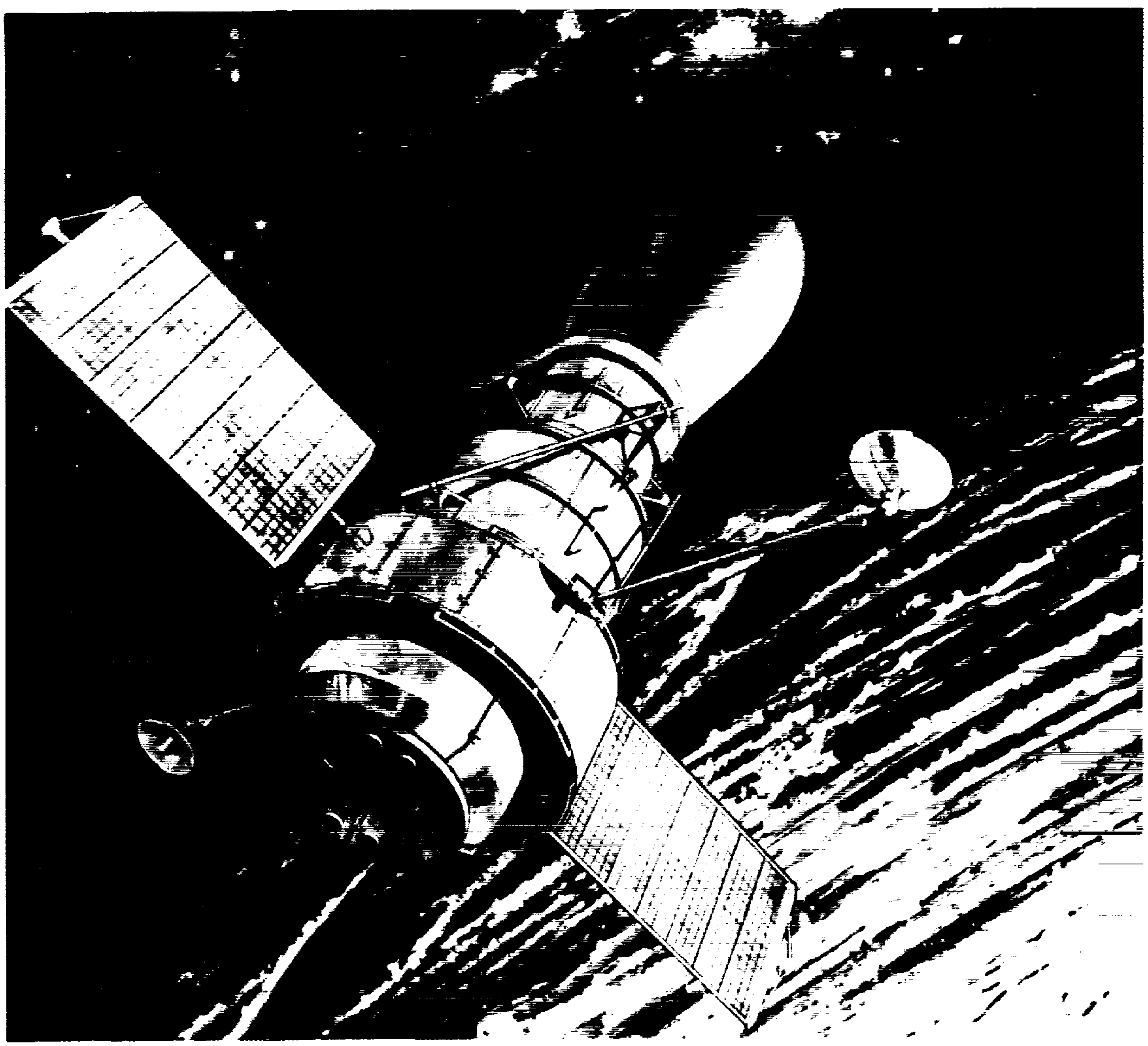

FIGURE 5.2. THE SPACE INFRARED TELESCOPE FACILITY (SIRTF)

This cryogenically-cooled observatory will be the major observatory for infrared astronomy.

With the dawn of the satellite servicing era, the MMS modular design becomes even more important to the payload user. Servicing capabilities incorporated in the MMS design provide the user with the ability to repair, replace, or resupply a satellite from either the NASA Space Station or the operational Space Transportation System. The ability to service an MMS type satellite was successfully demonstrated with the replacement of the Modular Attitude Control Subsystem during the Solar Maximum Repair Mission. This was accomplished as part of mission 41-C on the Space Shuttle Challenger. Figure 5.3 illustrates the modular design of the MMS.

Leased Services

A leased-service platform would provide flight opportunities in low Earth orbit for scientific, commercial, and government users on a leased or service-contract basis. The platform would employ standard modules for electrical power, communications and data handling, and attitude control, with additional modules being used to increase power, to achieve greater system accuracy and controllability, or to carry additional, smaller payloads. Systems such as these would be unmanned and initially Shuttle-tended until Space Station services would be available.

Proteus

The Proteus concept, currently being studied at GSFC, would be an autonomous spacecraft that provides full support to a variety of science investigations. It would have the propulsive capability, either integral or with an OMV, to leave the Space Station orbit and return at mission's end. The system configuration of the spacecraft would be a Shuttle-launched, modular, space-serviceable bus with the pointing flexibility of stellar-inertial, reaction wheel attitude control. Direct TDRSS links would allow complete independence from the Space Station between servicing visits. The anticipated spacecraft life would be greater than 10 years. This long life would be achievable through the repair and enhancement opportunities of a space-serviced modular design.

The significant, unique feature of Proteus is its attention to the interface between scientist and system at all levels: hardware, communication, data handling, software, and management. Transparency of the system is a prime Proteus development target. Principal Investigators would receive hardware that interfaces with the spacecraft, eliminating the need for interface design. Packetized data telemetry would permit each observer to customize data format and content for the individual experiment. Ground Service Equipment (GSE), like the spacecraft, would be modular and employ standard interfaces to enhance flexibility and adaptability.

PLATFORMS FOR EXPERIMENTS OF OPPORTUNITY

Often, new concepts for astrophysics instruments involve new technology to achieve higher sensitivity or higher resolution, and before the instrument can be approved for use in major observatories or other missions, it must be tested in space. Today, these opportunities are provided through NASA's suborbital program, carrying instruments in the top of the atmosphere and beyond with airplanes, balloons, sounding rockets, and Spartan carriers. New and important scientific knowledge usually results from these test flights, and during the Space Station era, it will be critical that opportunities continue to be made available to test new instrument concepts in space. We expect that the Space Station will make some of these opportunities possible.

FIGURE 5.3. MODULAR DESIGN OF THE MULTIMISSION MODULAR SPACECRAFT

Astronauts install the Attitude Control Subsystem Module in the Solar Maximum Mission.

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Space Station Spartans

A Spartan-class carrier would provide the capability of orbiting small payloads for brief periods (less than a week to as much as a month) at very low cost. Based on the Shuttle Spartan concept, the Space Station version would operate out of the Station, co-orbiting in the immediate vicinity. Among the main differences from the Shuttle version would be a quick-disconnect payload interface, improved serviceability, and rechargeable batteries.

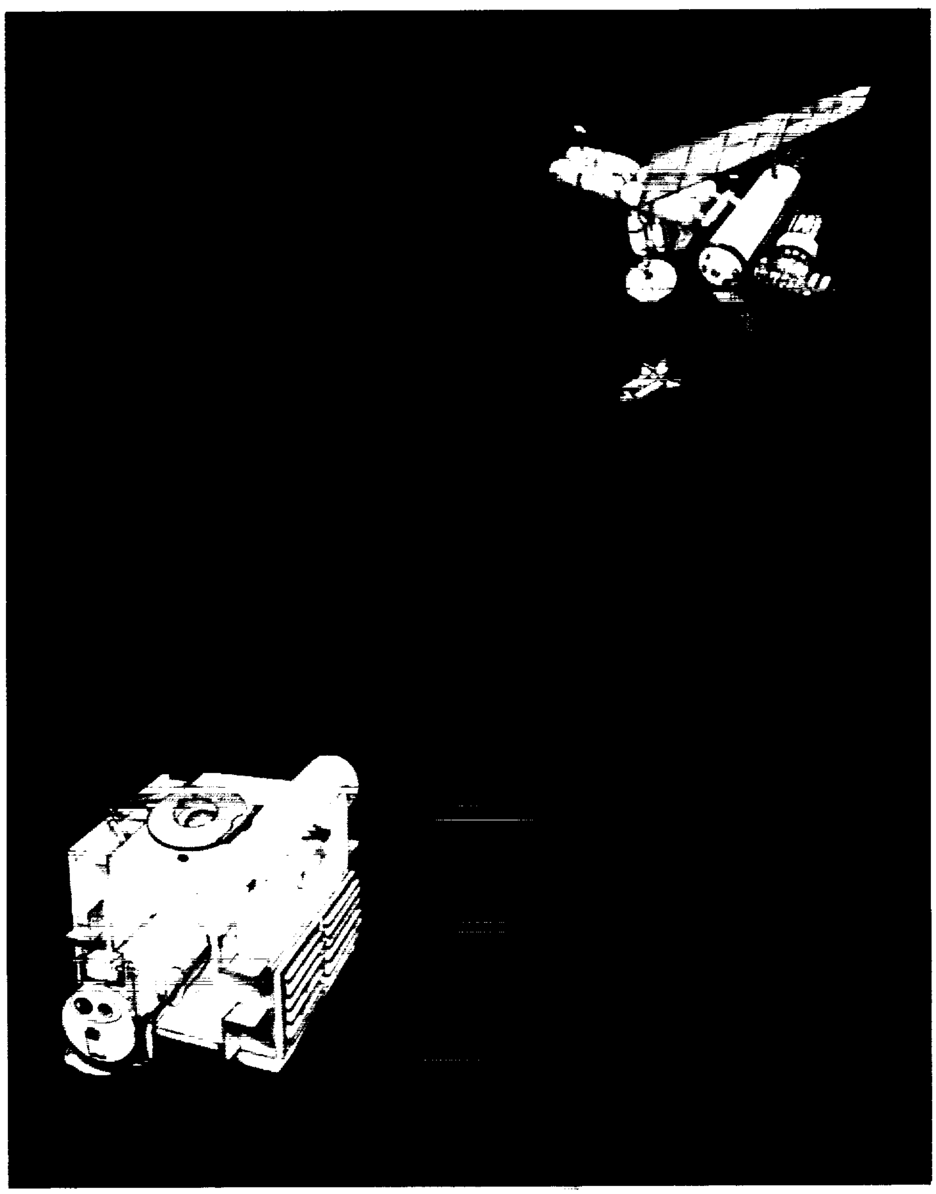

FIGURE 5.4. A SPACE STATION SPARTAN

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A Space Station Spartan would be an autonomous spacecraft that could co-orbit with the Space Station for periods up to a month. For electrical power, it would employ batteries but no solar arrays. With no communications link, data would be collected and stored on a large (10 Gigabit) tape recorder, using a programmable, fixed-format multiplexer. Operational control would be achieved with stored commands, and attitude would be controlled by a three-axis cold gas thruster assembly, using stellar-inertial (star tracker and gyros) sensors and microprocessors for control. Sun or Earth sensors are readily accommodated. No propulsion capability is planned, so the Space Station would have to provide deployment and retrieval support.

Payload modules for the Spartan would be delivered to the Space Station in the Shuttle orbiter. Each payload would be equipped with its unique "game cartridge" that controls pointing, power switching, data handling, and other mission-unique computer functions. As soon as the payload is attached to the Spartan via the standard interface, the game cartridge would be inserted, the batteries charged, the cold gas tanks filled, the tape recorder rewound, and a functional check-out performed. The Spartan would then be deployed for a few days in orbit. When Spartan is retrieved, the payload would be removed and returned to Earth. The observed data would be returned through the Space Station communications link.

CANDIDATE MISSIONS

We now discuss the candidates for platform-based moderate and Explorer class missions by scientific discipline rather than by system size and complexity. The objectives, current status, and intended mode of operation of each mission will be presented.

High-Energy Astrophysics

The following section describes several high-energy astrophysics missions that are well suited for operation on space platforms. The missions were selected as representative examples of usage of platforms in the context of the Space Station system, and no prioritization of missions is implied.

X-Ray Timing Explorer (XTE)

Fundamental physical information about neutron stars and black holes is contained in the dramatic changes in x-ray luminosity that occur in the brightest cosmic x-ray sources. Indeed, the discovery of periodic x-ray pulsations in a few sources was the key to their identification as neutron stars. Monitoring of the pulsations revealed Doppler shifts of the pulse period and, in a few cases, periodic eclipse-like disappearances of the x-ray source. These timing data were the critical information that revealed the true nature of the sources--binary star systems with mass from a normal star flowing onto a collapsed, compact companion star.

Black holes and neutron stars have the mass of an entire star within a radius of only 1 to 10 km. X-rays are produced in copious amounts as accreting matter is funneled and accelerated in their intense gravitational fields. Changes in their x-ray emission have been a rich channel of information for determining the fundamental properties of x-ray sources. The X-ray Timing Explorer (XTE) will provide the means to carry out detailed investigations of compact x-ray sources.

Mission Instruments. Three instruments have been selected for use in the XTE mission. Two of these, the Large Area Proportional Counter Array (LAPC) and the High Energy X-ray Timing Experiment (HEXTE), will study individual objects over long periods of time. The third, the Scanning Shadow Camera (SSC), will monitor the whole sky to alert the other instruments to the onset of unusual events that could be observed. The SSC will also accumulate, from its hourly samples, records of the behavior of the 200 brightest sources over the duration of the mission.

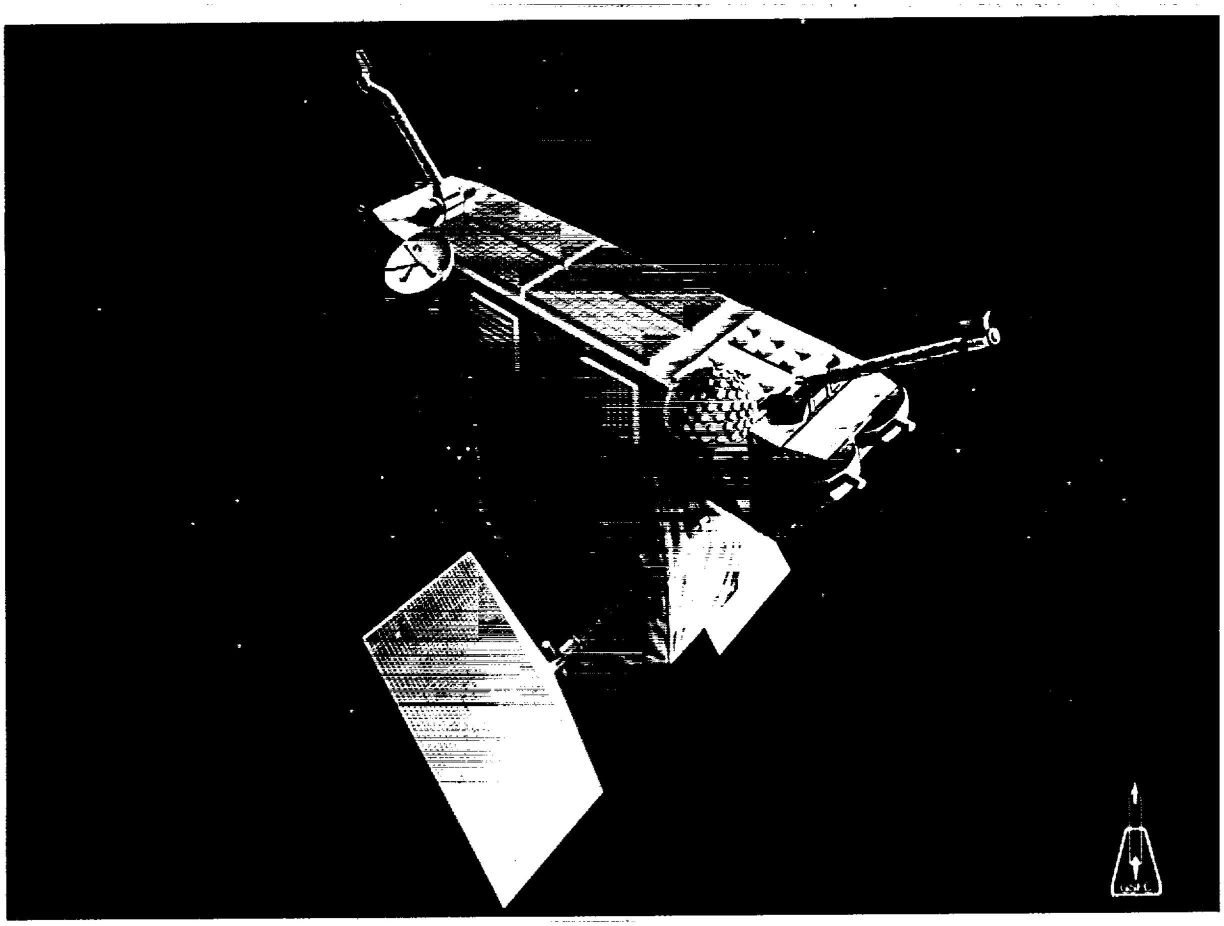

FIGURE 5.5. THE X-RAY TIMING EXPLORER

The instruments will have timing resolution of about 10 microseconds and will be ideal for measuring the energetic environments in X-ray sources. They will also be sensitive to features in the stellar spectra which indicate the magnetic and thermodynamic conditions in these sources.

Status. In 1985, we will choose among candidate spacecraft systems to carry XTE, ranging from an integrated free-flyer to a platform dedicated to the XTE mission. XTE has also been considered for the first mission to use the Proteus concept; its requirements are typical of the free-flying specialized missions that have high priority in NASA's astrophysics program.

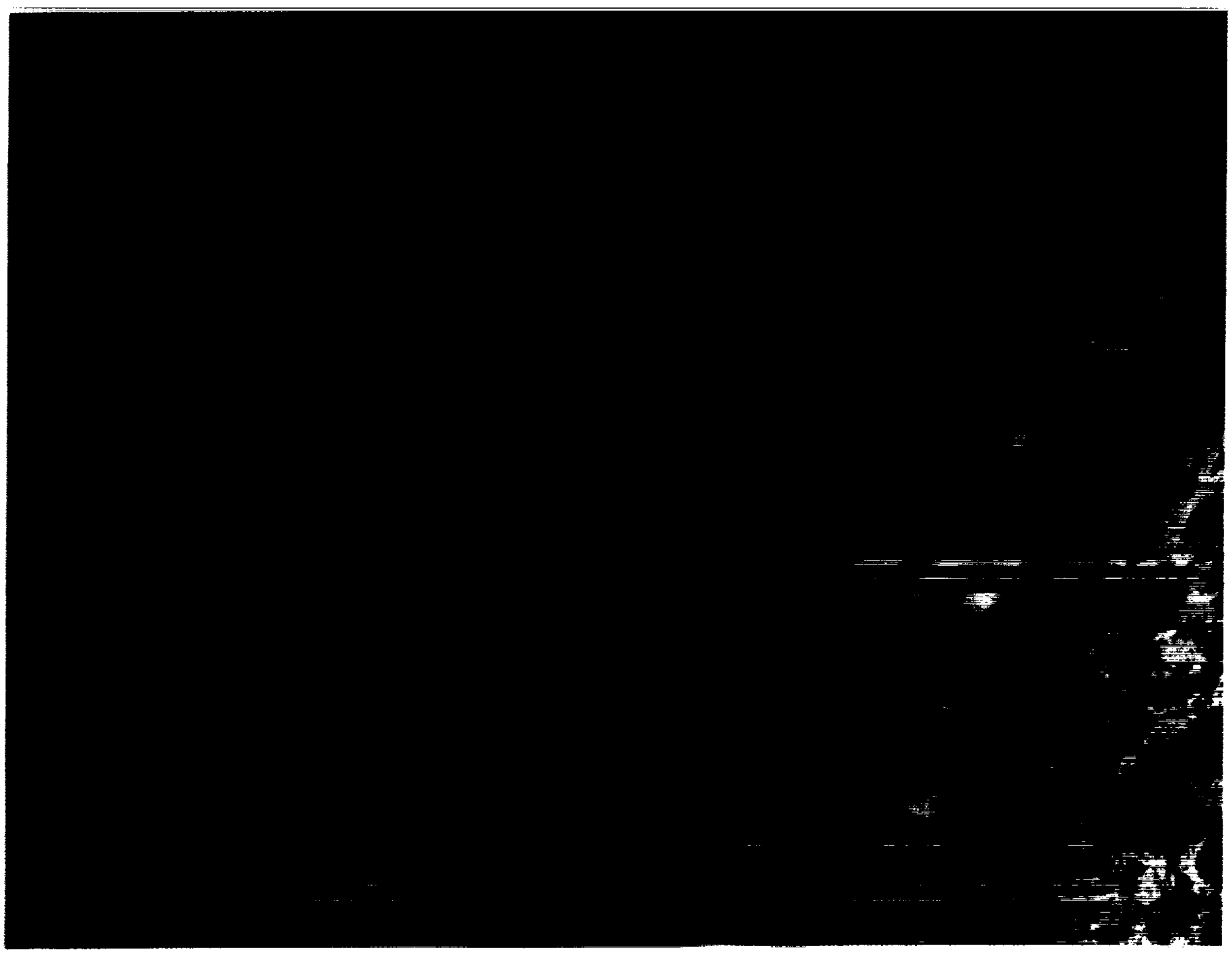

FIGURE 5.6 ARTIST'S CONCEPTION OF MATTER FLOWING FROM A NORMAL STAR INTO A BLACK HOLE, PRODUCING X-RAYS

XTE is being defined for launch in the early 1990's. It will be launched with the Shuttle and integrated with its platform in the Shuttle bay before it begins its 2-year mission. De-integration of XTE is likely to be one of the first platform tasks conducted at the Space Station as the platform is prepared for its second mission.

Operations. The scientific operations of the XTE mission will be conducted at the Goddard Space Flight Center in accordance with a scientific program determined by the Principal Investigators for each instrument and by Guest Investigators from around the world. In its primary mode of operation, XTE will point at a target for times ranging from 1 hour to several weeks. The LAPC will observe the target with high time resolution and low spectral resolution (15 percent at 6 keV) over the 2-60 keV range while HEXTE will alternate between viewing the target and viewing a nearby background region. SSC will scan the sky for new, transient sources and monitor the brightest sources.

High-Energy-Transient Explorer (HETE)

HETE is a candidate mission proposed to carry out a comprehensive, all-sky, broad-band study of a special class of short-lived but very bright cosmic X-ray and gamma-ray sources. These are called high-energy transient sources, and their behavior has defied our understanding: How an object that normally cannot be detected can suddenly outshine the entire universe in x-ray or gamma ray emissions and then vanish in a matter of seconds is very difficult to understand. This is a significant area of investigation in the study of high-energy astrophysical phenomena, because these sources are a critical probe of fundamental physics under extreme conditions.

Mission Instruments. High-energy transient sources are difficult to observe in detail and require specialized instruments to determine important physical parameters like temperature, density, and magnetic field strength right from the onset of the burst. To obtain this information, the HETE scientific payload will most probably consist of three instruments making measurements in the X-ray, gamma-ray, and optical bands. The instruments are:

- All-Sky X-Ray Camera
  The primary objectives of the All-Sky X-Ray Camera are to determine the location of gamma-ray and X-ray bursters very accurately and to measure the time histories and energy spectra of X-ray and gamma-ray bursts in the X-ray band. Using coded aperture imaging or grazing-incidence optics, the instrument will be expected to be able to view at least half the sky. It will be required to have enough sensitivity to detect a 10-second transient event over a range of energies.
- Spectrometer
  The spectrometer will measure transient-event spectra in the hard X-ray and gamma-ray range, from 10 keV to 10 Mev. With a field

of view that nearly fills the field of the All-Sky X-Ray Camera, the spectrometer will be surrounded by an active scintillator shield to suppress background from the spacecraft. Its other specific requirements are yet to be determined.

- Optical Transient Camera
  The Optical Transient Camera will be able to detect the optical transients that are likely to accompany gamma-ray bursts, and it will cover the same field of view as the All-Sky X-Ray Camera and the Spectrometer. The Optical Transient Camera will require enough sensitivity to detect a very low-energy event lasting only 1 second.

Status. The modest requirements of the HETE complement of instruments fit well within Proteus's capabilities. For data analysis, the pointing direction will have to be known accurately, although the imaging instruments will be able to self-calibrate on known bright X-ray and optical sources. Because of the relative rarity of these transient events, it should be possible to maintain a fairly low data-transmission rate (~30 kbps).

This mission would be integrated at the Space Station with a platform having at least the capabilities of Proteus. It would be brought to the Station by the Shuttle and possibly stored in orbit until the platform could rendezvous with the Station for de-integration and re-integration for its mission as HETE.

Operations. After it is transferred to its orbit, HETE would begin scanning the zenith around its orbit. When an x-ray or gamma-ray transient occurs, data on its location, its x-ray intensity profile, and its gamma-ray intensity profile would be stored along with accumulated spectra and optical information. At first, these data would be telemetered at a low rate, but after a year of operation, the system would be programmed to transmit an alarm message with essential information for action from other observatories, possibly including observatories on the Space Station.

If high-resolution, cryogen-cooled detectors are part of the payload complement, periodic (6 months - 1 year) replenishment of the cryogen will be necessary. The servicing capabilities of the Space Station should be ideally suited for carrying out this task.

High Throughput Mission (HTM)

HTM is an x-ray astrophysics facility in the moderate-mission class that will complement other x-ray observatories by having low angular resolution but very large collecting area. HTM will address scientific objectives that do not require very high resolution but for which sensitivity is crucial.

Mission Instruments. High sensitivity is needed to observe the regions of million-degree gas in our galaxy that are heated by supernova explosions and by stupendous winds from very young, massive stars. These regions are the major source of hydrodynamic pressure that sweeps up gas and dust in interstellar space to form the next generation of stars. High sensitivity is also needed to observe million-degree gas in coronae around nearby galaxies and in the immense regions of intergalactic space in clusters of galaxies. The distribution, composition, and temperature structure of this gas will reflect the dynamical history and evolution of the galaxies since they were formed.

To achieve high sensitivity for these faint, extended objects, up to 100 grazing-incidence x-ray telescopes will be grouped together, side by side, to provide an effective collecting area of 1 square meter or more. (In earlier descriptions, this mission was called the Large Area Modular Array of Reflectors). Because these sources are diffuse, high resolution in imaging can be sacrificed to facilitate ease of production for the hundreds of x-ray mirrors that will be needed. Three concepts for the mirrors are under study.

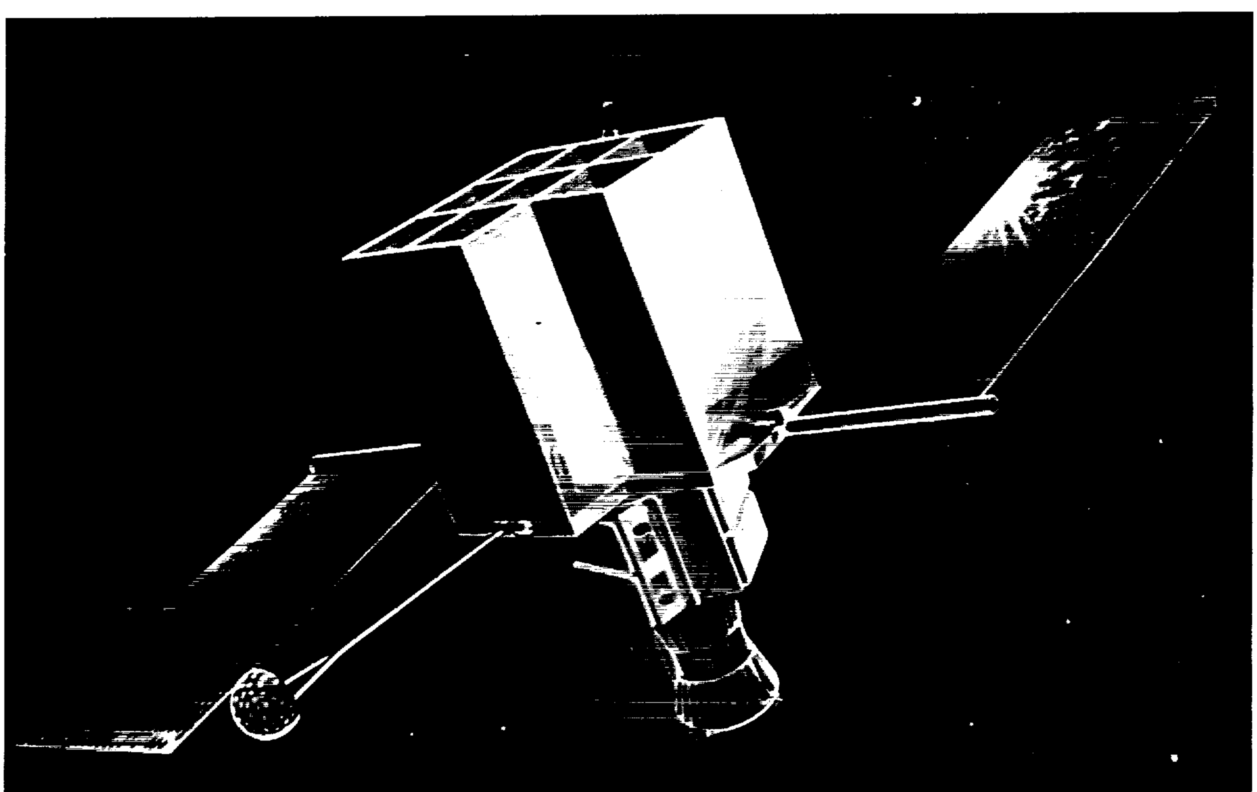

FIGURE 5.7 THE HIGH THROUGHPUT MISSION ON A DEDICATED "SPACE PLATFORM"

At the foci of the telescopes, x-ray sensors will collect the images and record the spectra of the cosmic x-ray sources. Imaging data will show the density of the sources, while the spectra will show the temperature (at low spectral resolution) and composition (at moderate and high spectral resolution) of the sources. The composition of gas heated by supernova explosions should reveal the extent of nuclear processing that has occurred in the inner portions of our galaxy as compared to the outer portions, while the composition of intergalactic gas will show evolution since nearly the beginning of time.

Status. HTM is in the class of moderate missions that will require spacecraft capabilities comparable to those available from an MMS. The mission will require a lifetime of 5 to 10 years, and it is likely that the first integration of HTM with its platform will only involve about half of its telescope modules. As more modules are developed, they will be integrated with the mission at 2-year service intervals.

This integration scenario will only be possible if there is a Space Station, with the necessary platform servicing and integration support capabilities, available to support the mission.

Operations. HTM will conduct a series of observations proposed by investigators from around the world. HTM is a good candidate for a joint mission between NASA and the European Space Agency, and if the program develops as a cooperative effort, control will probably be shared. Many of the detectors in HTM will require replenishment of gases and cryogens that are necessary for instrument operation. The service interval will be on the order of 2 years and will require transportation from HTM's operational orbit to the Station and back.

Advanced Low-Energy Gamma-Ray Explorer (ALEGRE)

Among the astrophysical phenomena that produce low-energy gamma-rays are the annihilation of electrons and anti-electrons, from the decay of radioactive nuclei, and the motion of energetic electrons in extremely strong magnetic fields. In addition, there are numerous continuum sources of broad-band emission and emission far from thermal equilibrium as extremely energetic electrons collide with visible light, radio waves, and even weak, interstellar magnetic fields. Taken together, this wide variety of emission mechanisms provides a powerful set of diagnostic tools for the study of high-energy astrophysical objects, such as compact binary systems, pulsars, novae, supernova, and active galactic nuclei.

Future observations from the Gamma-Ray Observatory (GRO) can be expected to increase considerably the number and variety of objects that will require detailed observations in this energy range. To perform such detailed studies, instruments with significantly improved spectroscopic and imaging capabilities will be needed. ALEGRE is a mission proposed to carry instruments with excellent resolution to complement GRO and to further investigations begun by the GRO survey.

Mission Instruments. Whether the payload consists of a single instrument combining spectroscopy and imaging capabilities or two instruments, each optimized for one of these objectives, is a question that cannot be answered until a more detailed study is carried out. For the purpose of this document we have taken a baseline of two instruments. The first is a high-resolution spectrometer with a modest angular resolution, and the second is a high-angular-resolution scintillator experiment using coded-aperture imaging. (Because gamma rays are too energetic to be reflected, even at grazing angles, an image will be formed by blocking out parts of the field of view. This is called coded-aperture imaging.) Together, these instruments will allow simultaneous high-sensitivity measurements of narrow-line, broad-line, and continuum radiation.

Status. This mission would be part of the Explorer series, and in the Proteus concept, it would replace another Explorer instrument that had completed its mission after 3 or 4 years of operation.

In this concept, the Proteus platform would be retrieved from its operational orbit with the OMV and brought to the Space Station, where the old instrument would be removed and placed in storage until a later Shuttle would be available to return the instrument to the ground. An earlier Shuttle would have brought up the ALEGRE instruments which would be taken out of storage, charged with cryogens, and integrated with the Proteus platform. Finally, the platform and ALEGRE would be transported by the OMV to their operational orbit where the missions would begin.

Operations. The combined instrument complement would be operated under ground control to conduct surveys or carry out detailed studies of individual sources. The choice of observing strategy would depend on the imaging capabilities such as field of view and angular resolution. The required observing time on any given source or region of the sky would typically be from a few days to a few weeks.

Changes in the observing program could be accomplished by utilizing the servicing capabilities of the Space Station to reconfigure the coded-aperture imaging system and, possibly, to replace the cryogens for the detectors.

Solar Physics Missions

The primary thrust of solar physics in the era of the Space Station will be to develop instruments for the Advanced Solar Observatory attached to the Space Station itself. (These instruments are described in Volume 2.) However, there is one mission that has been defined by the solar physics community as having very high priority, the Solar Corona Diagnostics Mission, which we describe in this section.

In some ways, the corona of the sun is as mysterious to us now as it was to earlier civilizations who were surprised to discover a glowing halo around the Sun during rare total eclipses. Now we know that in white light we are seeing sunlight reflected off electrons in a plasma having a temperature of a million degrees, and with x-ray spectroscopy, we have actually observed the ions that have lost these electrons, allowing us to derive the temperature, density, and velocity structure of the corona.

With this information, we have been able to calculate how much power it takes to sustain the corona and to drive the solar wind, but so far, we have not been able to find out how the power is delivered. The most popular theory of 10 years ago is now known to be wrong, and we are left with the puzzle. We have defined the Solar Corona Diagnostics Mission (SCDM) to help us understand the origin of the corona and the acceleration of the solar wind.

Mission Instruments. The instrumentation for SCDM was selected in 1981. A White Light Coronagraph will measure the electron density and the evolving form of the corona, record transient events, and permit solar physicists to infer the global magnetic structure from the density measurements. A Soft X-ray Imaging Telescope will show the evolving form of the corona, provide plasma temperatures and pressure, and record the coronal manifestations of newly emerging magnetic flux. The third instrument, a Resonance Line Coronagraph, will measure coronal plasma properties and

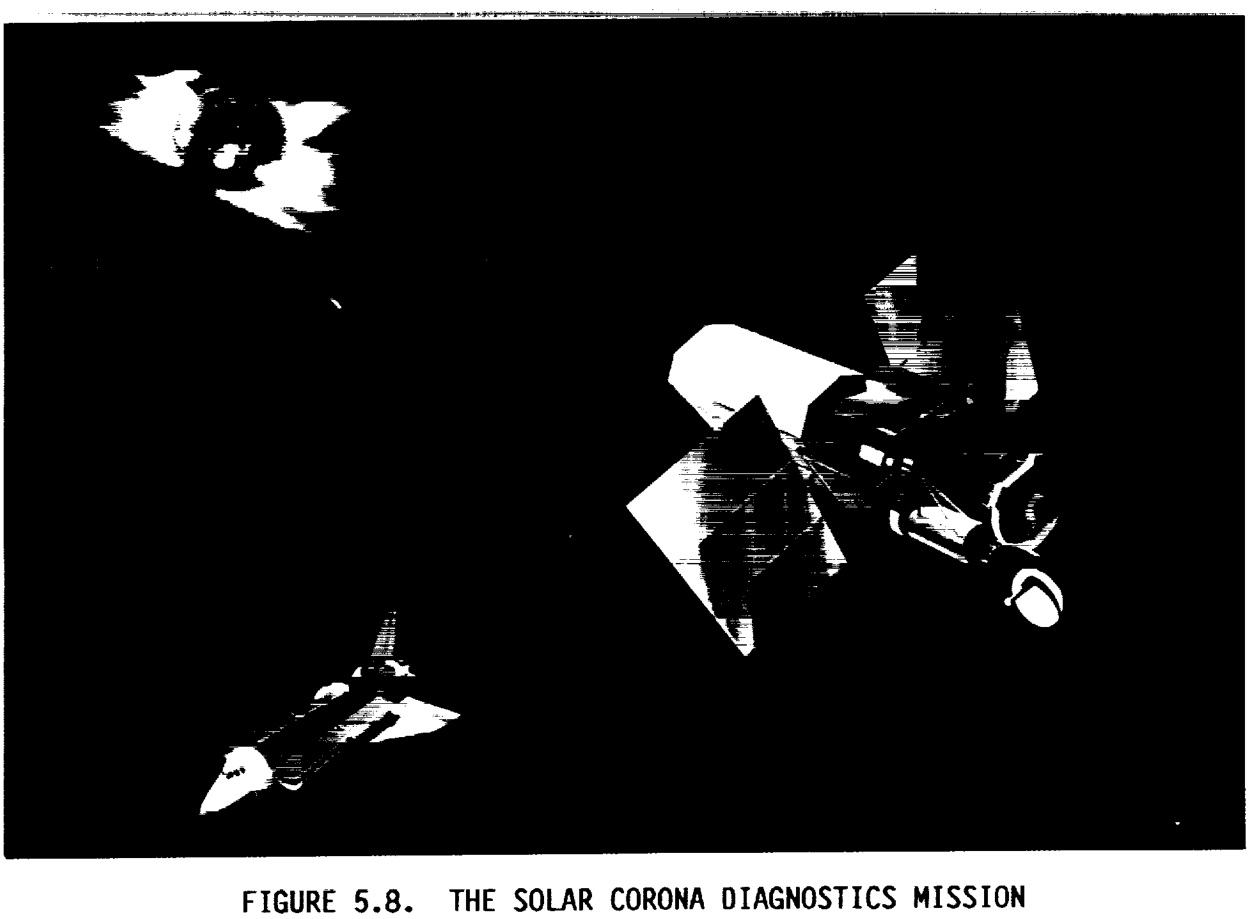

FIGURE 5.8. THE SOLAR CORONA DIAGNOSTICS MISSION

systematic velocities as a function of distance. The fourth instrument, an Extreme Ultraviolet Diagnostic Spectrometer, will measure systematic velocities and plasma properties of the corona, from the coronal transition region into the cooler, denser portions of the Sun's atmosphere, in order to define the varying lower boundary of the inner corona and solar wind. The fifth instrument will be a magnetograph to obtain the magnetic field at the photosphere. The magnetic field governs the form and possibly the overall dynamics of the corona, and this information will be essential for the success of the mission.

Status. SCDM can be accommodated with any platform that has at least the capabilities of Proteus. In the Proteus concept, SCDM is a candidate to be the first mission on the second Proteus platform, and, like XTE, it would probably be integrated with its platform in space.

Operations. The minimum mission duration for SCDM is 3 years. It will be operated as a facility, with data distributed to investigators around the country. There are no consumables, and after 3 years, we expect to bring the mission back to the Space Station for de-integration and replacement with another mission.

Astronomy

The following section describes four astronomy missions that will fly on individual, standardized space platforms. Again, the missions selected for description are not meant to imply any special priority, but rather to indicate the broad range in astronomy missions that are best suited for a platform and to show the broad range in benefits provided by the Space Station system. These benefits include the use of free-flying platforms, the availability of the Orbit Transfer Vehicle, and the servicing capability.

Far Ultraviolet Spectroscope Explorer (FUSE, Columbus)

The universe is composed almost entirely of the two elements hydrogen and helium; the heavier elements that we encounter on Earth every day are present in only the minutest amounts when we look at the universe as a whole. Most astronomy so far has relied upon using the scarce, heavy elements as tracers of the physical state of matter, because hydrogen and helium have their fundamental atomic transitions far in the ultraviolet, beyond the reach of ordinary telescopes. To examine the fundamental emissions from hydrogen and helium, FUSE has been designed as a very powerful observatory capable of making fundamentally new and important observations of nearly all classes of astronomical objects, from local solar system objects to cosmological phenomena.

Mission Instruments. The FUSE instruments will consist of a telescope and two spectrographs designed to conduct observations in the far ultraviolet range. Because normal-incidence optics do not work effectively at short wave-lengths, the telescope will be designed to reflect the ultraviolet light at grazing angles. Two spectrographs provide the high resolution necessary to extract physical information concerning important galactic and intergalactic phenomena such as the state of Jupiter's plasma torus that envelops Io's orbit, the global balance of energy in the coronae of stars, the violent forces acting on the gas between the stars, and the deuterium content of intergalactic material. This last observation is extremely important because deuterium (hydrogen with both a proton and a neutron in its nucleus) is a sensitive probe of nuclear conditions during the formation of the universe.

Status. Like XTE and SCDM, FUSE is likely to be one of the first missions for a dedicated platform, and this makes it likely to be integrated with its platform in space, possibly in the Shuttle. The opportunity to place FUSE on a separate platform, retrievable and serviceable by the Space Station, introduces new possibilities for FUSE. Not only can the cost be reduced through removal of redundant components, but the versatility of the experiment can be extended as well. For example, the spectrograph described above could be exchanged for a low-resolution, grazing-incidence design which would use the same telescope and pointing system. A few years later, a short-wavelength, high-resolution instrument could be flown. Such an approach could keep FUSE on the cutting edge of astrophysics for decades and extend the use

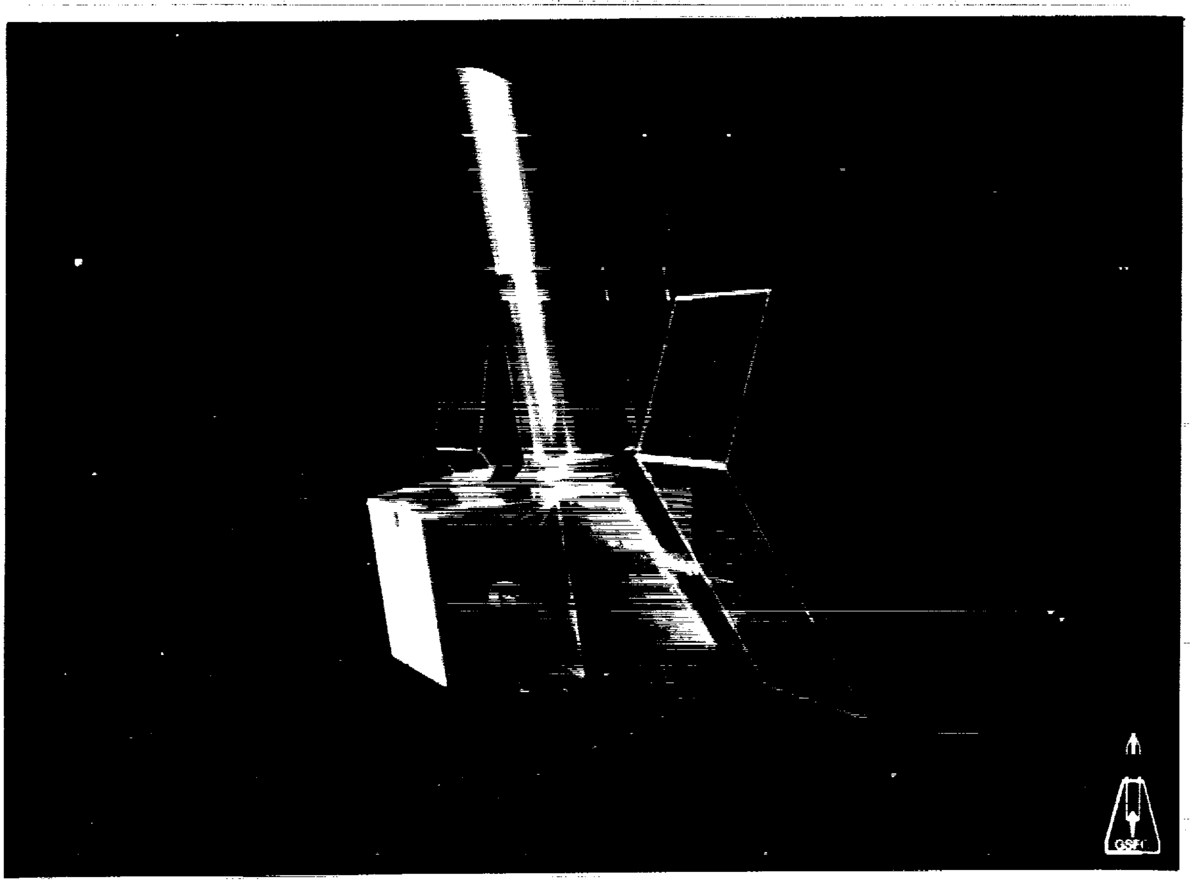

FIGURE 5.9. FAR ULTRAVIOLET SPECTROSCOPY EXPLORER

of the telescope far beyond anything possible with a dedicated observatory design.

Operations. The observatory will be operated in a sequence of preplanned observations selected from proposals submitted to NASA. Discussions are being conducted to determine whether there is international interest in making FUSE a joint program; if there is, operations may be jointly shared with the international participants.

Starlab

The Hubble Space Telescope is designed to obtain high resolution data over a wide wavelength band, but the types of observations it will perform are limited by its narrow field of view. Since many observations require a large field of view, the Starlab space-based telescope will be developed to fill this need. Current plans call for NASA to be responsible for the space platform, launch, and mission operations, and for international participants to provide the telescope, scientific instruments, and integration of the Starlab facility.

Mission Instruments. Starlab will be a free-flying, 1-meter astronomical telescope that will obtain wide-field images and long-slit spectra at ultraviolet and visible wavelengths. A Direct Imager Camera will view the central field of the focal plane and record the entire field with little degradation in image quality. The camera will employ filters for spectral definition and a prism for low-dispersion spectra over the full target field. A spectrograph will provide spatially-resolved spectrograms along the length of the slit. The area surrounding the field viewed by the scientific instruments will be used to track stars with the Fine Guidance System.

The Starlab instrumentation makes it possible to study objects with large apparent diameters such as nearby galaxies, clusters of galaxies, supernova remnants, or comets. It will also be used to obtain large statistical samples, such as distance indicators in nearby galaxies, or to isolate targets in crowded fields, such as Cepheids in nearby galaxies. In addition, Starlab will perform survey work such as searching for supernovae in distant galaxies. Thus, this instrument will complement other space telescopes by providing independent observations of certain objects and by identifying sources for more detailed study.

Status. The long mission duration, susceptibility to contamination, and stringent pointing requirements all call for a free-flying platform to accommodate Starlab. Additionally, Starlab capabilities will be enhanced by the ability to refurbish the mission at the Space Station, and, ultimately, to place the Starlab in geosynchronous orbit to improve its efficiency.

The goal for in-orbit operation life is 5 years, with a total multimission lifetime of over 20 years. On the first mission, planned for the mid-1990s, Starlab will carry the Direct Imager Camera as the sole scientific instrument. On subsequent missions, a refurbished Starlab facility will carry the Long-Slit Spectrograph as well.

Operations. Starlab would be operated by the United States and its international partners as a joint facility, with program options coordinated among the nations.

Orbiting Very-Long-Baseline Interferometry Observatory

Very-long-baseline interferometry (VLBI) techniques have been used by radio astronomers over the past decade to obtain maps of celestial radio sources at previously unrealizable levels of angular resolution--about 1000 times better than the resolution achieved with optical photographs or conventional radio interferometers. Satellite-borne VLBI terminals could

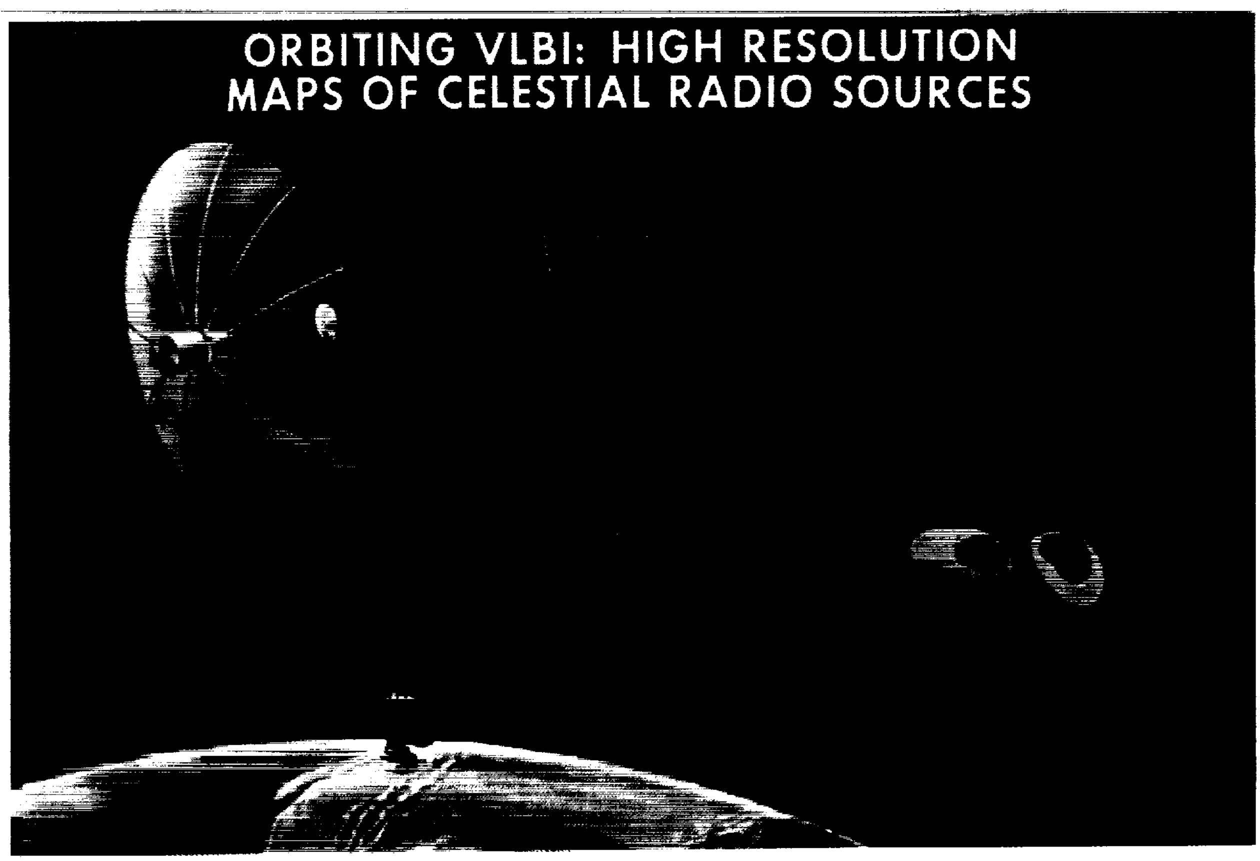

FIGURE 5.10. ORBITING VLBI: HIGH-RESOLUTION MAPS OF CELESTIAL RADIO SOURCES

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COLOR PHOTOGRAPH

provide maps of compact celestial radio sources with finer resolution, less ambiguity, and more efficiency than earth-bound VLBI techniques. High spatial and temporal resolution observations would help unravel the physical processes that govern some of the most enigmatic classes of celestial objects.

Mission Instruments. An orbiting VLBI mission called Quasat has been proposed as an international joint endeavor in space radio astronomy. The Quasat system requires a sufficient signal-to-noise ratio to allow for source detection. Receivers and feeds would be at the focus and operate at frequencies of 22 GHz, 5 GHz, and 1.6 GHz. The spacecraft will utilize a ground-based hydrogen maser frequency standard to derive the onboard frequency reference. Data rates of 144 mbps are expected; all data will be handled in real time.

Status. These spacecraft requirements appear to be within the capabilities of the MMS. The reflector and components which dominate Quasat's configuration could be made compatible with the MMS standard interface.

Because Quasat's orbit is expected to differ substantially from that planned for the Space Station, no interaction with the Space Station in terms of servicing or assembly is foreseen. However, prototype systems can be developed and tested by deploying them from the Space Station.

Operations. In addition to quasars, exotic stars such as pulsars, X-rays stars, flare stars, and SS-433 type objects will be observed. These all display highly energetic phenomena. The time scales for variation are very short, in some cases only hours, so that observations of these stars is an ideal application of Quasat's rapid mapping capability. Quasat's sensitivity would allow the study of the fine structure of about 10,000 celestial objects, including:

- 7000 quasars
- 1500 galactic nuclei
- 1000 "empty field" sources
- 400 interstellar masers
- 100 radio stars

Astrometric Explorer

An exciting prospect for a specialized space platform mission is the Astrometric Explorer, an optical telescope capable of measuring star positions very precisely. With high-precision position measurements, the parallax and proper motion of the most distant stars in our galaxy can be measured. These measurements will allow the dynamics of our galaxy to be established and correlated with optical and radio maps.

The scientific benefits that may be expected from this precision include the precise measurement of the following:

- Absolute distances of galactic stars
- Distances to interstellar absorption features
- Structural properties of spiral arms

- Galactic dynamics
- Binary masses
- Mass-color-luminosity relation of main sequence stars
- Space motions of nearby external galaxies.

The Astrometric Explorer is well suited to installation on an MMS or Proteus-class platform. A mission duration of 3-5 years should be adequate to achieve the goals of the Astrometric Explorer Mission.

SUMMARY

We believe that the Space Station will allow significant increases in the efficiency with which we conduct the Astrophysics Program by augmenting the servicing capability for observatories and platforms. The continuum of platforms, along with effective Space Station servicing, will provide a proper mix of flight opportunities for free-flying science experiments.

WORKSHOP ON

ASTROPHYSICS UTILIZATION OF THE SPACE STATION

Panel on Space Platforms for Astrophysics

Dr. Louis J. Kaluzienski, Chairman

Dr. Paul A. Blanchard	Dr. Richard A. McCray
Dr. Roger D. Bourke	Dr. Enrico Mercanti
Dr. Jesse D. Bregman	Dr. Robert Novick
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Mr. William D. Hibbard	Mr. David H. Suddeth
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